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Temperatures and precipitation totals over the Russian Far East and Eastern Siberia: long-term variability and its links to teleconnection indices

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Abstract

The present study examines the spatial-temporal regime of the mean monthly temperature (MMT) and monthly precipitation (MPT) anomalies over the Russian Far East and Eastern Siberia for the period 1949–2003. The original data were analyzed spatially by means of complex principal component analysis and temporally by means of the maximum entropy method and traditional Fourier spectral analysis. The interannual variability in these anomalies can be represented by the single dominant modes. These dominant modes oscillate with periods of about 2–3 yr and 6–8 yr that are accompanied by statistically significant changes in such monthly teleconnection indices, as the Arctic and North Pacific Oscillations.

1 Introduction

The variations of surface-air temperature and precipitation are of vital social and economic importance (Watson et al., 2001). However, there is uncertainty in the question how climatic systems evolve. The potential reliability of climate models can be tested by comparing simulated climate variability with observed. So, the study of observed climate variability may be summarized as a climate model verification problem (Majda et al., 2001).

The physical processes that are responsible for climate evolution are fundamentally non-linear. The most widespread linear correlation techniques are unable to clearly recognize the climatic signal in the short and noisy data series. Methods based on modern spectral analysis techniques are relatively free from these disadvantages. Hancock and Yarger (1979) used classic Fourier spectral analysis to investigate the relationship between the Zurich annual sunspot number and state monthly mean temperature and precipitation for the contiguous United States. Schonwiese (1987) applied the cross-spectral analysis to provide physical reasons for periodic signals included in temperature series. Benner (1999) measured the coherence by cross-spectral anal-

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ysis to explore the connections between the prominent oscillations in temperature in central England and solar activity.

At present the tandem “spectral analysis + principal component analysis” is more preferable than other methods (Ghil and Yiou, 1996). Suitable significance criteria for spectral and principal component analysis are more developed as distinct from wavelet analysis.

In this work the complex research of the spatial-temporal regime of the mean monthly temperature (MMT) and monthly precipitation (MPT) anomalies is carried out for the Russian Eastern Siberia and Russian Far East for the period 1949–2003.

2 Data

At present the gridded precipitation and temperature data are available from National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) or the web-site (<http://www.cru.uea.ac.uk/~mikeh/>) at the University of East Anglia (Hulme and Jones, 1993). However, it is well known that the interpolation of data, especially precipitation, from individual station locations to a regular grid proved to be critical (White, 2000), and, therefore, we used the stations data only.

Time series of monthly precipitation and monthly mean temperatures are determined by 56 stations around Eastern Siberia and the Far East (Fig. 1) approximately between 41° N–60° N and 100° E–144° E. Each 55-year series begins in 1949 and ends in 2003. Data series were obtained from the Department of Long-Term Weather Forecast (Far East Regional Hydrometeorological Research Institute, Vladivostok, <http://www.hydromet.com>).

From studies (Barnston and Livizey, 1987; King et al., 1998; Thompson and Wallace, 2000) we know that the different teleconnection indices can reflect the major part of multi-scale variability of the atmospheric dynamics. After that, many investigators showed that variations in the teleconnection indices involve surface air temperature and precipitation (Thompson et al., 2000; Cavazos, 2000; Rodriguez-Puebla et al.,

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2001). In the present work, we approximated the East Asian monsoon activity via circulation teleconnection indices, i.e. the North-Pacific (NP) index and Arctic Oscillation (AO) index. These teleconnection circulation indices are distributed by NCEP–NCAR (Bell and Halpert, 1995).

5 The North-Pacific Oscillation is a decennial-scale mode, that is, the North-Pacific index is the leading mode of October–March sea surface temperature variability poleward of 20° N (Gershunov and Barnett, 1998; Biondi et al., 2001).

10 The Arctic Oscillation index is constructed by projecting 1000 mb height anomalies poleward of 20° N onto the loading pattern of the AO. The loading pattern of the AO is defined as the leading mode of classic principal component analysis of monthly mean 1000 gPa height during 1949–2003 period.

15 We used the technique of data preparation described in Yuan and Martinson (2000). The precipitation and temperature anomaly time series, i.e. after removing the seasonal cycle, contained inter-annual and longer variability as well as linear trends. Then we removed any linear trend at every station point.

It is well known that monthly precipitation time series do not have a Gaussian function distribution, so a square root transformation was applied to the data (Krokhin, 2000).

3 Methods

20 The complex principal component analysis (CPCA), maximum entropy method (MEM) and traditional Fourier cross-spectral analysis techniques have been used to studying traveling phenomena in the anomaly time series and their connectivity with different teleconnection indices.

25 The anomaly time series is affected by strong spatial-temporal (spectra-like) noise and locally quasi “errata” values. Fortunately, the temporal variability of anomaly time series was found spatially coherent at scales larger than the spatial noise (Genthon et al., 2003).

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We used complex time series analysis which allows decomposing space-time signals into different modes when the variance is spread over a number of frequencies. The complex principal component analysis is a method which allows introduction of a temporal dimension in the classical principal component analysis for studying traveling waves in the atmosphere (Horel, 1984; Davis et al., 1991). The complex principal component analysis method consists of transforming a spatial-temporal data set into a complex signal. In the study this was done using Hilbert transform of real time series computed for instance using the time-domain filtering Herrmann's technique (1969). The variance can be decomposed into different modes, as for a classical component analysis, but the modes are no longer associated with only static variability but with a dynamic one, taking into account the time evolution on the variability.

Further, the spatial patterns of only two dominant complex principal components were complex rotated orthogonally by the Varimax method (Kaiser, 1958; Bloomfield and Davis, 1994). The orthogonal rotation solution is "... less dependent on the domain of the analysis" (Horel, 1984, p. 1665).

For carrying out the CPCA we used the author's package based on IMSL programs (International Mathematical and Statistical Library, 1982).

A main limitation on the performance of complex empirical orthogonal function analysis is that modal spatial patterns from a time domain analysis of wide-banded signals should be interpreted cautiously (Merrifield and Guza, 1990). Therefore, the anomaly time series were filtered by a Butterworth's low-pass symmetric filter (Rabiner and Gold, 1975) to eliminate noise with periods less than 1 year prior to the variability analysis. In order to minimize Gibbs's end effects during spectral analysis the first and last 10% time steps of time series were tapered using a portion of a cosine bell distribution (Bloomfield, 2000).

Multivariate analysis methods, especially the complex empirical orthogonal function method, assume the data to be complete. When there are gaps the resulting complex correlation matrix shall be ill conditioned, it will be even not a positive definite and the numeric procedure will give several small negative eigenvalues. A way of overcoming

this problem is to fill the missing data using an adequate method. In the study we recovered missing data with the help of simulation techniques based on Bayesian inference for multivariate data with missing values. The computational routine NORM is described by Schafer (1997). NORM (version 2.02) is a Windows 95/98/NT program for multiple imputations of incomplete multivariate data. The program is available on personal Schafer's site (<http://www.stat.psu.edu/~jls/>).

Although a CPCA is a very powerful method for identifying waves or modes, an advantage of spectral analysis is that the techniques for determining the statistical significance of the results are better developed. In the present paper, the maximum entropy method and the traditional cross-spectral analysis have been used to find connections between anomaly time series and some circulation indices. Maximum entropy spectral analysis is a technique that can be used for relatively short and noisy time series when one needs more spectral resolution than provided by classic Fourier spectral analysis (Press et al., 1992). The maximum entropy method will tend to strongly localize spectral peaks. In practice, we used it in conjunction with traditional Fourier spectral analysis (Bloomfield, 2000).

Cross-spectral analysis of coherence was obtained by Fast Fourier Transform using the Welch's periodogram technique (Welch, 1967; Jenkins and Watts, 1968). Coherence can be regarded as evidence against meteorological distinctness (Brillinger, 1981).

In order to establish the significance of periodic signal components in the analyzed time series in the presence of white noise, Siegel's test has been used. Siegel's test is the most powerful test against many periodicities, i.e., for cases in which up to three periodic components are present in a time series (Percival and Walden, 1993).

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4 Complex principal analysis on precipitation and temperature anomaly time series

In an attempt to identify coherent spatial/temporal substructure in the anomaly time series, a CPCA was applied to identify traveling and standing waves (Horel, 1984).

5 Earlier, Salinger (1980a, b), Domroes et al. (1998), Varlamov et al. (1998), Rodrigues-Puebla et al. (2001) established that time series of temperature and precipitation anomalies in the different geographical regions could be represented with relatively few empirical orthogonal function modes. Later, White and Cherry (1999) found out that interannual variability in temperature and precipitation time series in
10 New Zealand can be represented by a single dominant mode.

Here, we also demonstrate that interannual variability in Eastern Siberian and Far Eastern time series of temperature and precipitation anomalies can be represented by the single or two dominant modes.

CPCA of temperature anomalies yields the first mode explaining 55% of the total
15 low-pass interannual variance. The complex empirical orthogonal functions are presented here in terms of its amplitude (arrow length) (Fig. 2a) and phase (arrow direction) (Fig. 2b). The vector pointing upwards (downwards) indicates that real and imaginary eigenvector components are in-phase (out-of-phase), a vector pointing to the right (left) indicates that the real part lags the imaginary on $1/4$ of a period. For
20 example, the clockwise vector rotation from west to east indicates that the wave travels eastward (Horel, 1984; Turre et al., 1999). In our case, the phase angle over our pattern remains quasi-constant, indicating that the temperature anomalies evolution is stationary. So, the temperature variability over our domain can be represented by a standing wave component.

25 However, “..... precipitation variability is relatively elusive ... ” (Gentson et al., 2003; citation from “Interannual Antarctic tropospheric circulation and precipitation variability”, 2003). Mode discrimination and sorting through CPCA is thus more difficult and unreliable for precipitation than for temperature. Therefore we analyzed

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the first mode only. The remaining part of the total interannual variance is too inconsistent and noisy to be further analyzed with confidence. The dominant mode of the precipitation anomalies pattern (Figs. 3a, b) represents 22% of the total low-pass interannual variance. The relative parity among the weights in the real and imaginary components of the precipitation dominant mode (not shown) indicates that precipitation anomalies have a greater propagational character associated with them than do temperature anomalies. In other words, this mode is a superposition of progressive and standing waves. Some eastward and equator directed spreading of the climatic signal occurs over our domain. This is shown by a clockwise rotation of vectors over Eastern Siberia and the Far East. The eastward and equator directed propagation is consistent with the direction of propagation in atmospheric anomalies associated with the Arctic Circumpolar Wave. This is true for the middle latitudes in the Southern and Northern Hemispheres both (White and Cherry, 1999; White, 2000; Ambaum et al., 2001).

The real components of the temperature and precipitation anomaly time series for dominant complex principal modes lags the imaginary components by approximately 2–3 yr (≈ 23 –34 months) with coherence levels 0.91 and 0.87, respectively (Fig. 4). Real and imaginary component time series are orthogonal to each other (not shown), however these are not Hilbert transforms to each other (Horel, 1984). Note, that White and Cherry (1999) recommended to use a temporal lag between real and imaginary components in statistical climate prediction models.

The dominant complex principal component temporal phase for the precipitation and temperature anomalies (here not shown) decreases with time for the most part of our time domain but it increases in some intermediate periods. On the one side this can be explained by the fact that analyzed time series consist of anomalies of varied time scales. On the other hand, if the phase increases or decreases monotonically from 0 to 2π over π , it can be inferred that a certain cyclicity exists in the anomalies time series (Venegas et al., 1998; Turre et al., 1999). We shall demonstrate below that this may be explained when significant periodic signal components in the temporal coefficients

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of complex principal modes of analyzed time series exist.

5 **Cross-spectral analysis of the dominant complex principal modes of the temperature and precipitation anomaly time series and the teleconnection indices**

5 Earlier, Rodriguez-Puebla et al. (2001) carried out the cross-spectral analysis of the dominant ordinal principal modes of the precipitation over the Iberian peninsula and North Atlantic Oscillation index. In this paper it was emphasized, that "... when two time series have significant peaks at particular frequencies and the peaks are coherent, the local and global information constitutes a true climate signal" (citation from: Rodriguez-Puebla et al., 2001). In this study we used the approach of the paper (Rodriguez-Puebla et al., 2001), to analyze the dominant complex principal modes of the anomaly time series and its relationship to the North-Pacific index and Arctic Oscillation index.

15 The dominant complex principal modes of temperature and precipitation anomalies reveal two significant spectral peaks with the period of $\approx 6-8$ yr (72-96 mo) and the quasi-biennial oscillation with the period of 2-3 yr ($\approx 23-34$ mo) (Figs. 5a, 6a, 7a). The coherence between the dominant complex principal modes of temperatures and precipitation anomalies and the Arctic and North Pacific Oscillations suggest, in general, that the presence of these oscillations at 6-8 yr and 2-3 yr must be signals of variations because they are coherent at about 0.21 squared correlation. The critical value for coherency estimates is 0.16 at 95% significance level (Brillinger, 1981) (Figs. 5b, 6b, 7b). It is remarkable, that, interconnections are more stable for the dominant complex principal mode of precipitation anomalies, than temperature anomalies (the variant "complex principal mode of precipitation anomalies and arctic oscillation" is not shown).

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The results in the present study possibly suggest that the Far Eastern mean monthly temperature and monthly precipitation anomaly time series can be associated with the quasi-biennial oscillation and are coherent with the stratospheric extra-tropical quasi-biennial oscillation and “El Nino-Southern Oscillation”. The Southern Oscillation is the strongest climatic signal in the tropics. El Nino and La Nina are opposite phases of the “El Nino-Southern Oscillation” cycle (Troup, 1965; Philander, 1990). The stratospheric extra-tropical quasi-biennial oscillation is most easily identified as an alternation of descending westerly and easterly wind regimes in the lower stratosphere with a period varying from 22 to 34 months (Reed et al., 1961).

Earlier, the analogous results were found in surface temperature over the United States (Rasmusson et al., 1981), in annual precipitation over Far East (Eremin, 1982), for African rainfall time series (Ropelewski and Halpert, 1987), for Indian rainfall time series (Mooley and Parthasarathy, 1984). Shen and Lau (1995) found a quasi-biennial oscillation mode in East Asian summer monsoon rainfall. Lu (2003) found the biennial oscillation signal in monthly station pressure, temperature and precipitation data in Taiwan. A midlatitude quasi-biennial oscillation was clearly identified by an in surface level pressure field over the northern hemisphere (Trenberth, 1975; Trenberth and Shin, 1984). It was found that the quasi-biennial oscillation of sea level pressure corresponds to the fluctuations of the midlatitude wavenumber-3 planetary wave. Gong and Ho (2003) showed that Arctic Circumpolar Wave statistically significant influences upon East Asian Monsoon by way of north-south movement of the middle latitude zonal jet over East Asia.

The decadal oscillation (≈ 8 yr) is less revealed than the quasi-biennial oscillation. Nevertheless, the existence of this oscillation is also confirmed by many investigators. For the European region, e.g., Rodriguez-Puebla et al. (2001) registered the oscillation with the period of 8-yr between the North Atlantic Oscillation Index and winter precipitation over the Iberian Peninsula.

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For our geographical domain, Hanawa (1995) found that the Sverdrup transport and Far East Zonal Index fluctuate with the 6–8 yr. periodicity over the Northwest Pacific. Tourre et al. (1999) emphasized 6–8 yr. periodicity in surface level pressure and sea surface temperature anomalies over North Pacific. Ponomarev et al. (1999) also estimated the oscillation period of sea surface temperature anomalies over North Pacific as 6–8 yr. Wang et al. (2004) examined variability of temperature and precipitation over China and found that quasi-biennial oscillations are stronger in East China, than in West China.

The anomalies in atmospheric pressure, temperature and rainfall have similar statistically significant periodicity on the different interannual timescales in different East Asian regions. The present study does not pursue the purpose to analyze the physical nature of these interrelations. Different assumptions were suggested by many investigators. For example, Nakamura (2002) accentuated the main role of the storm activity for the East Asian monsoon intensity. We shall note only, that it is necessary to search for possible explanations, apparently, in the nature of climatic fluctuations, in the so-called mechanism of long time memory in climatic system (von Storch and Zwiers, 1999). Research of the mechanism of long time memory is the further basis for climate modeling and, subsequently, forecasting.

7 Conclusions

We examined the spatial-temporal regime of the mean monthly temperature and monthly precipitation totals anomalies over Russian Eastern Siberia and the Russian Far East for the period 1949–2003. We found that interannual variability in Eastern Siberian and Far Eastern time series of temperature and precipitation anomalies can be represented by the single or two dominant complex principal modes. It has been suggested that these modes have similar statistically significant periodicity on the different interannual timescales in different East Asian regions. Whether these modes are likely to be physically important in the earth's atmosphere is an open question,

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however.

Thus, the further studies of climate of Eastern Siberia and the Far East must be closely joined with studies of the West Pacific monsoon, El Nino–Southern Oscillation, surface air temperature and precipitation variations in the western Pacific and surrounding oceans, the tropospheric/stratospheric biennial oscillation, and the South Asian Monsoon.

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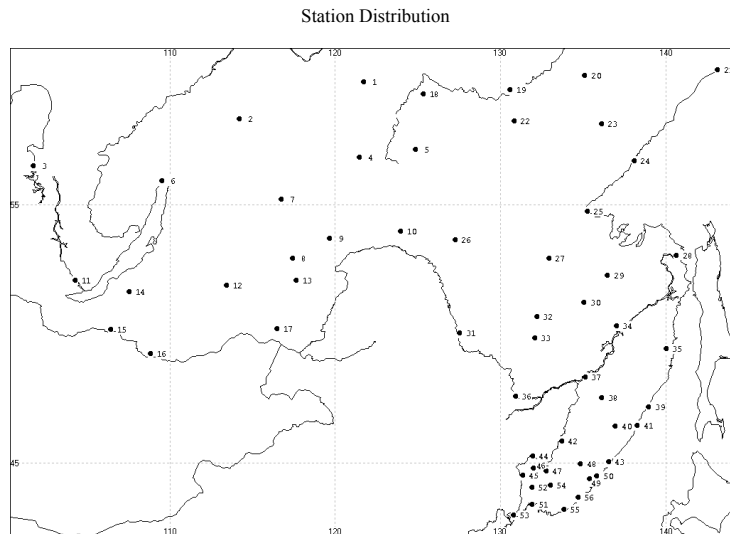
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Station Names

1. Djikimda	15. Kjahta	29. Im. Poliny Osipenko	43. Ternej
2. Bodajbo	16. Menza	30. Hularin	44. Turij Rog
3. Bratsk	17. Borzja	31. Blagoveshhensk	45. Pogranichnyj
4. Ust-Nukja	18. Aldan	32. Chekunda	46. Astrahanka
5. Chulman	19. Uchur	33. Sutor	47. Spassk-Dal'nij
6. Nizhne-Angarsk	20. Ust-Yudoma	34. Komsomol'sk-na-Amure	48. Roshhino
7. Kalakan	21. Ohotsk	35. Tumnin	49. Bogopol'
8. Zilovo	22. Chulbu	36. Ekaterino-Nikol'skoe	50. Rudnaja Pristan'
9. Mogocha	23. Nelkan	37. Habarovsk	51. Vladivostok
10. Skovorodino	24. Ayan	38. Gvasugi	52. Timirjazevskij
11. Irkutsk	25. Chumikan	39. Zolotoy Cape	53. Pos'et
12. Chita	26. Zeya	40. Ohotnichij	54. Anuchino
13. Sretensk	27. Ekimchan	41. Sosunovo	55. Preobrazhenie
14. Ulan-Ude	28. Nikolaevsk-na-Amure	42. Dal'nerechensk	56. Margaritovo

Fig. 1. The locations of 56 stations where temperature and precipitation was measured over Eastern Siberia and the Far East from 1949 to 2003.

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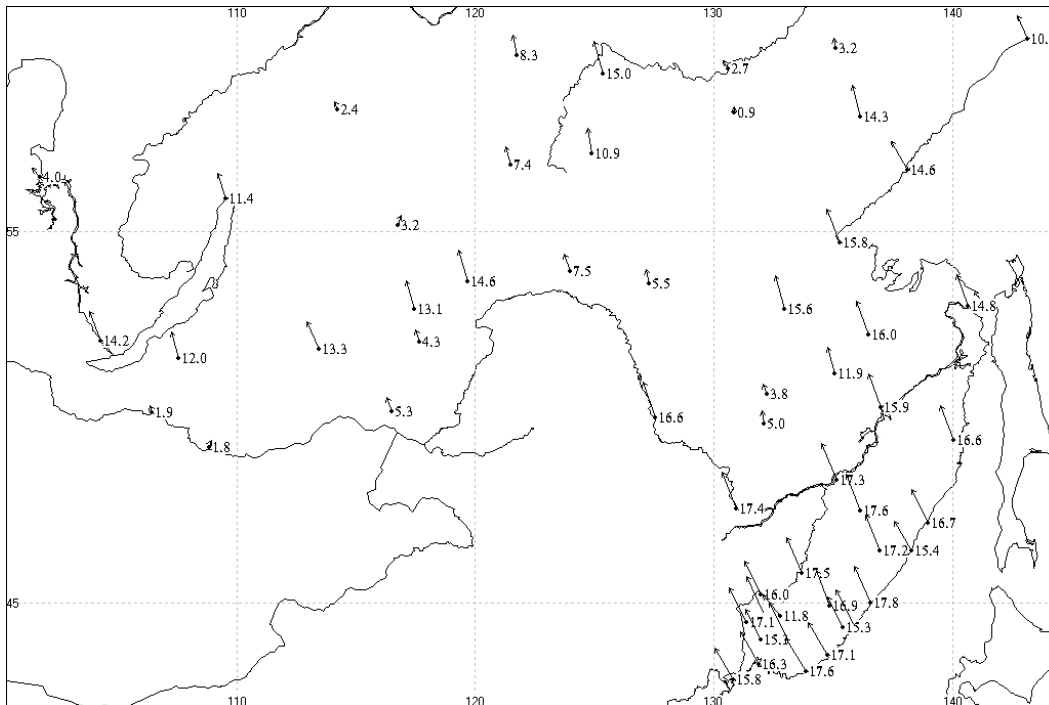


Fig. 2a. First complex principal pattern (55% of total variance) of the Mean Monthly Temperature anomalies.

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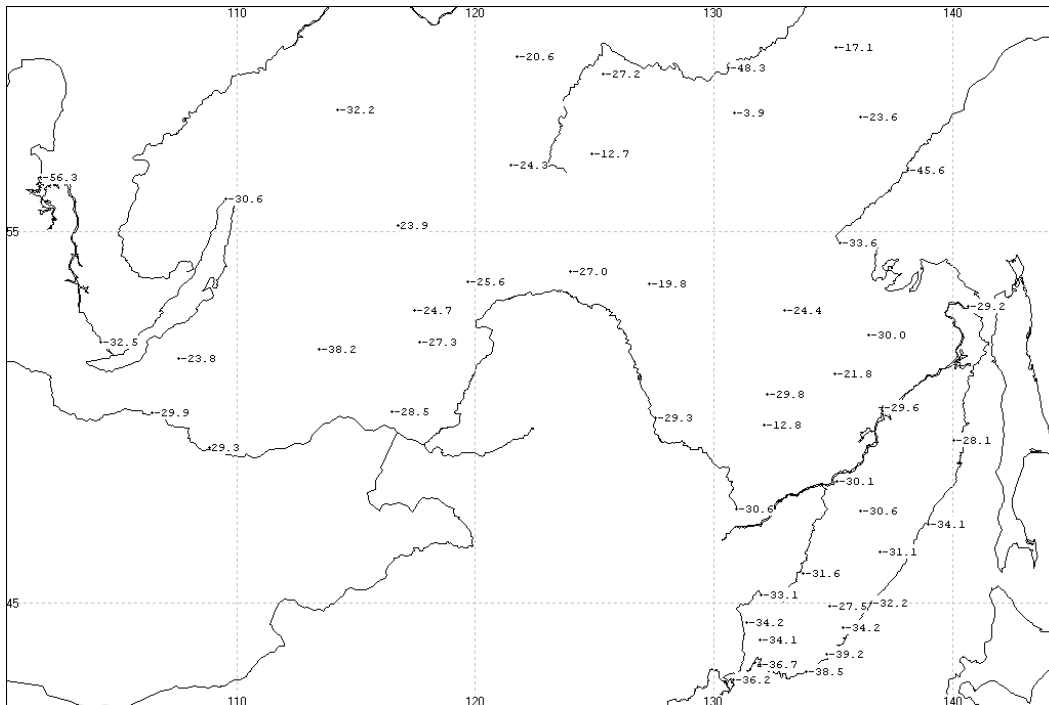


Fig. 2b. Spatial phase (in degrees) of the complex principal component of the Mean Monthly Temperature anomalies.

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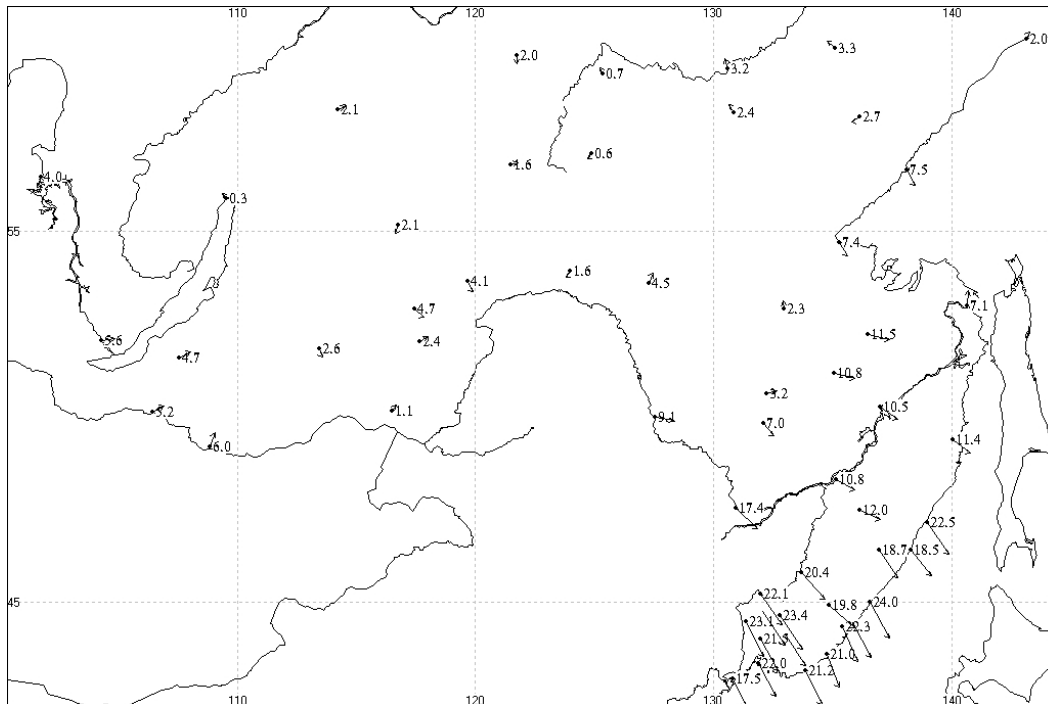


Fig. 3a. First complex principal pattern (22% of total variance) of the Monthly Precipitation anomalies.

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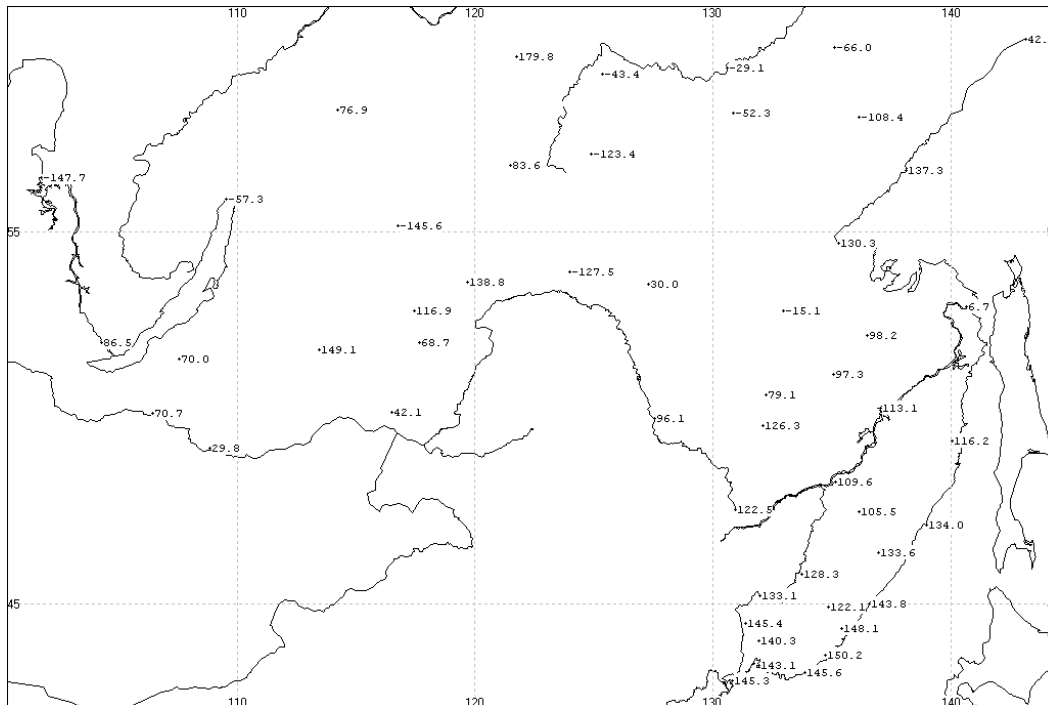


Fig. 3b. Spatial phase (in degrees) of the complex principal component of the Monthly Precipitation anomalies.

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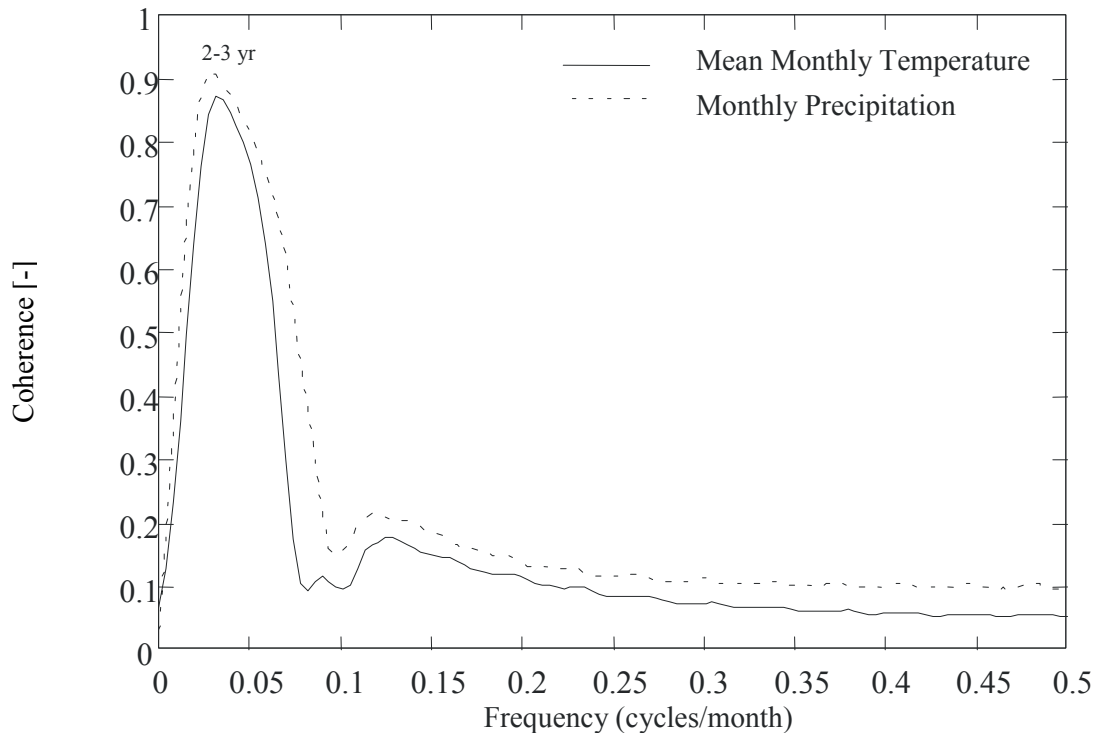


Fig. 4. Coherence between the real and imaginary parts of the temporal coefficients of the dominant principal components for the Mean Monthly Temperatures and Monthly Precipitation time series.

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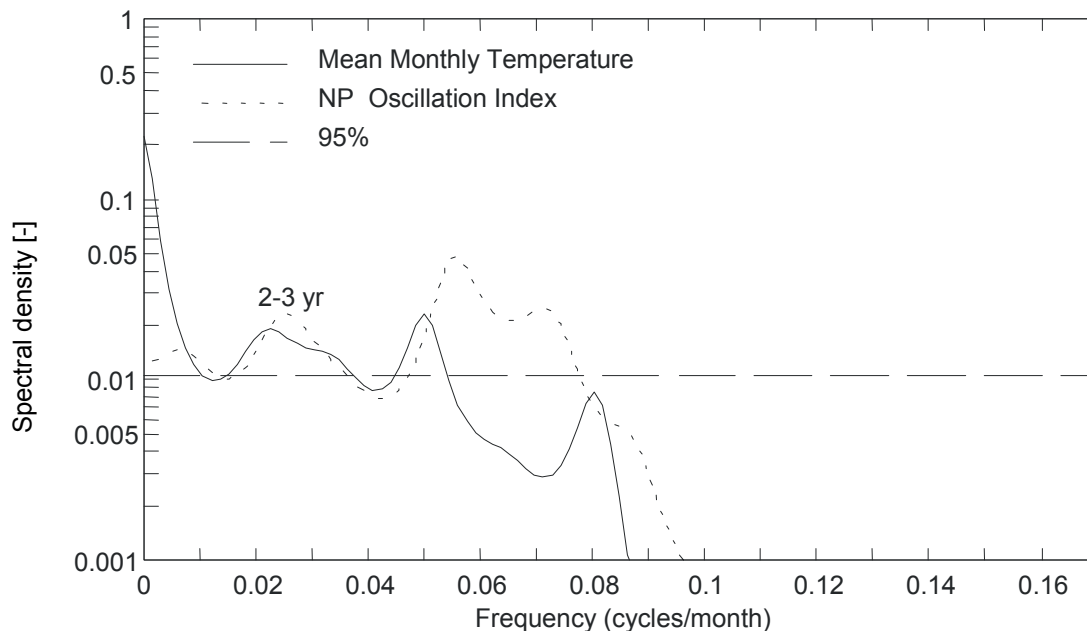


Fig. 5a. Spectra of the dominant complex principal mode of Mean Monthly Temperatures and the NP Oscillation Index.

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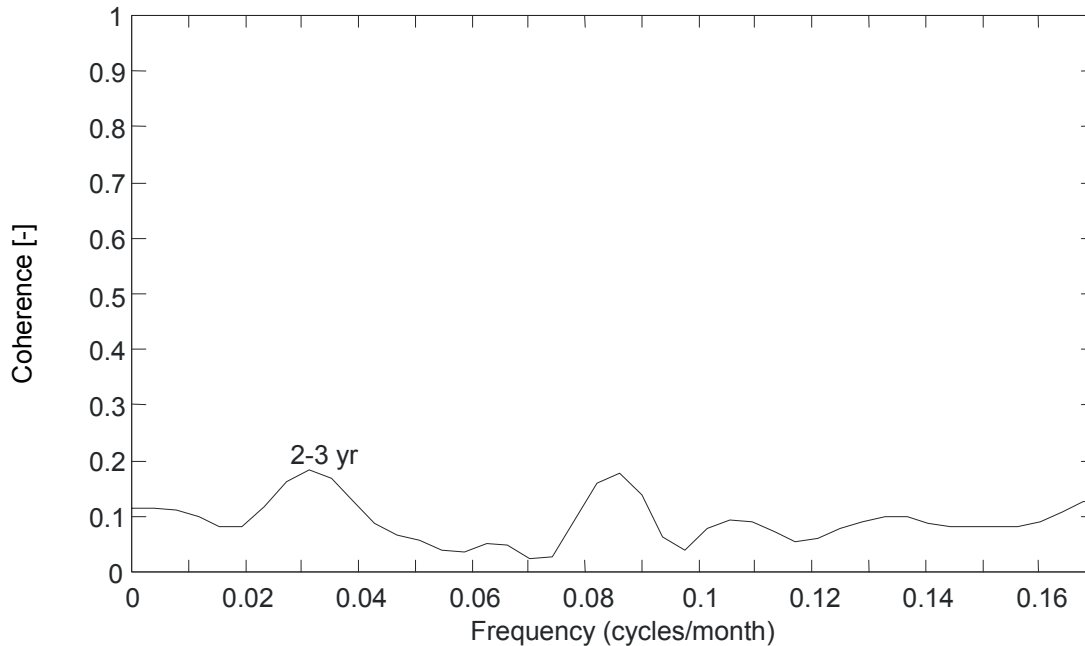


Fig. 5b. Coherence between the dominant complex principal mode of Mean Monthly Temperatures and the NP Oscillation Index.

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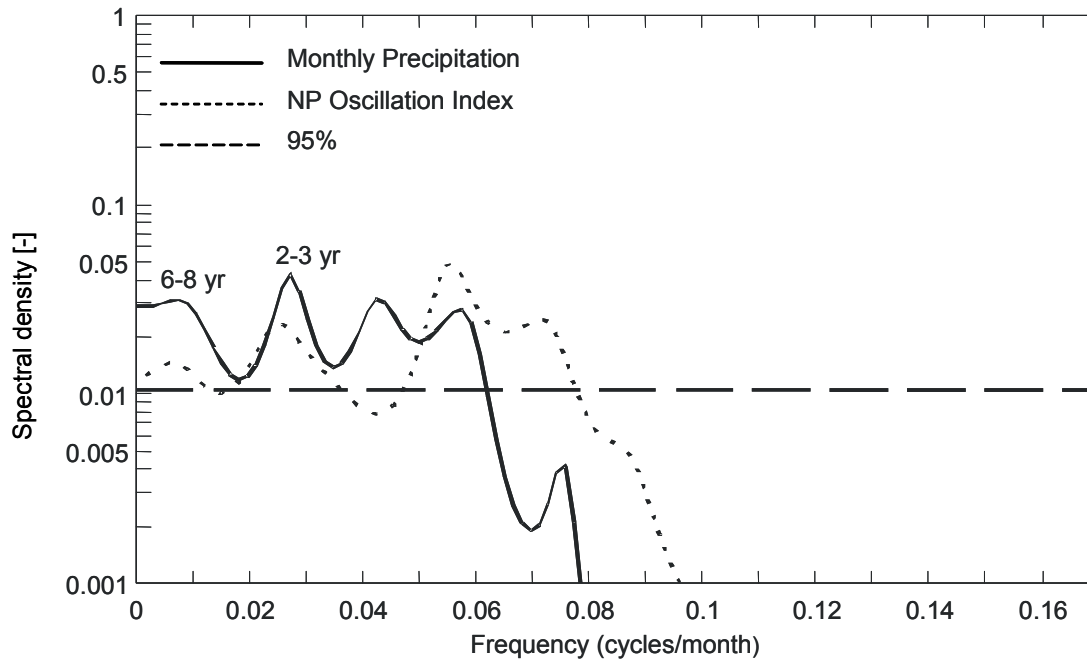


Fig. 6a. Spectra of the dominant complex principal mode of the Monthly Precipitation and the NP Oscillation Index.

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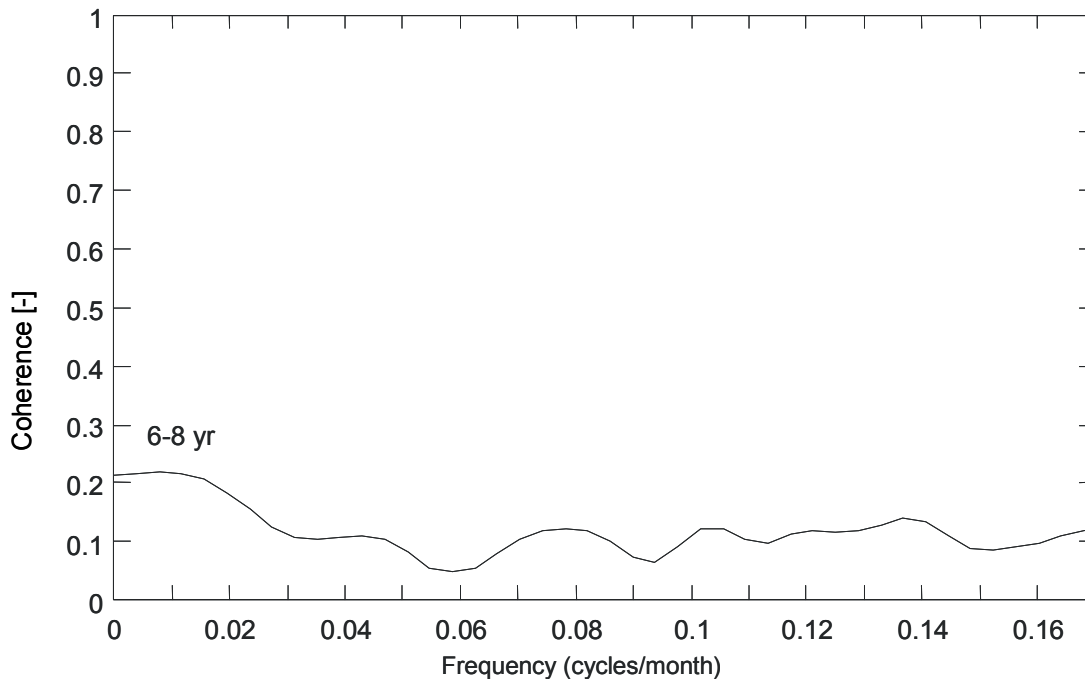


Fig. 6b. Coherence between the dominant complex principal mode of the Monthly Precipitation and the NP Oscillation Index.

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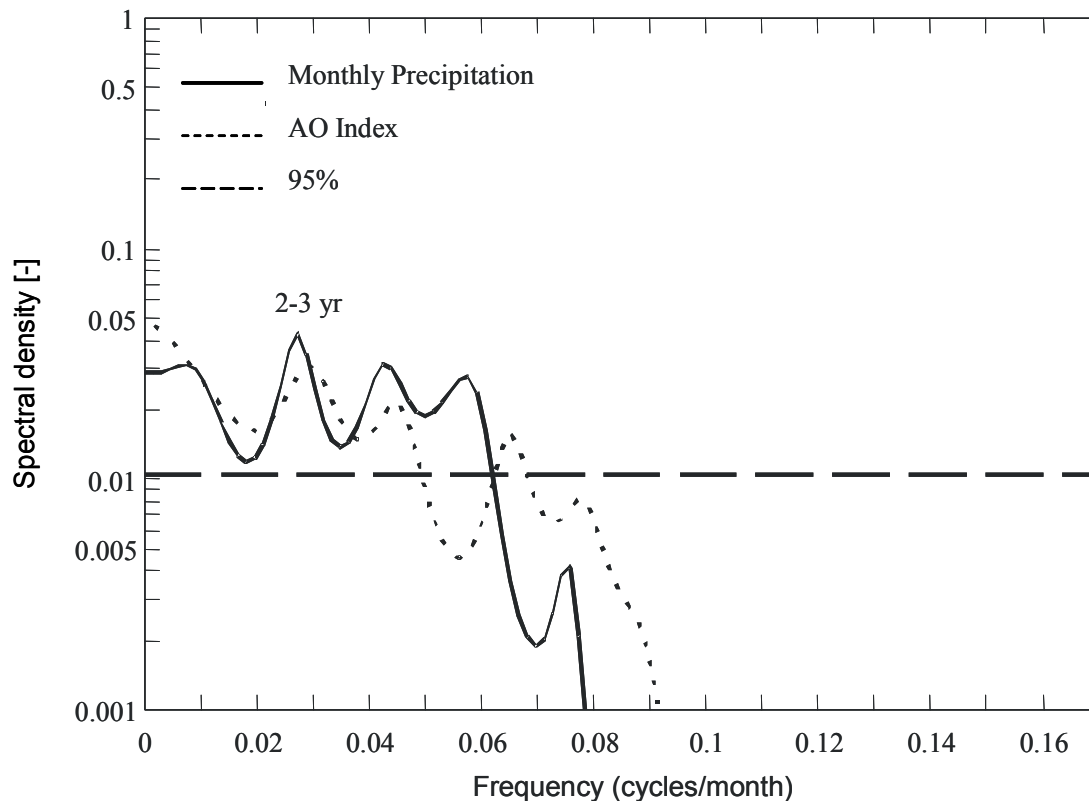


Fig. 7a. Spectra of the dominant complex principal mode of the Monthly Precipitation and the AO Index.

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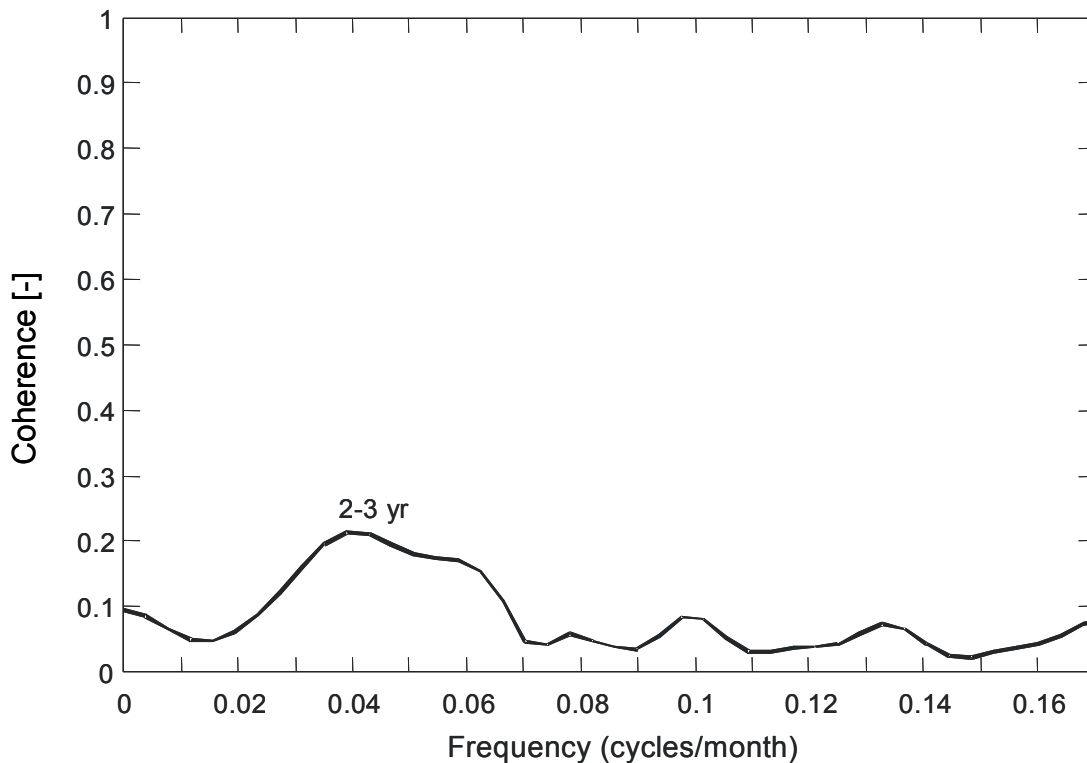


Fig. 7b. Coherence between the dominant complex principal mode of the Monthly Precipitation and the AO Index.

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